91602
new 82-10

LEGAL NOTICE

This report was prepared by Ontario Hydro and, while effort has been made to assure the accuracy and applicability of the material contained herein, neither Ontario Hydro nor any person acting on its behalf:

(a) makes any warranty, express or implied with respect to the use of, or damages resulting from the use of, any information, apparatus, method or process disclosed in this report or that such use may not infringe privately owned rights; or

(b) assumes any liabilities with respect to the use of, or for damages resulting from the use of, any information, apparatus, method or process disclosed in this report.

COMPLIMENTARY COPY
Please Credit Ontario Hydro Research if Reproduced in Whole or in Part

ontario hydro
research division

ENERGY EFFICIENCY OPPORTUNITIES IN ARC WELDING

Report No 91-150-K

P.Y.Y. Maak
Engineer - Welding
Metallurgical Research Department

ABSTRACT

This report describes an investigation in the assessment of energy efficiency opportunities in arc welding. An energy-efficiency testing procedure was designed and used to evaluate the energy efficiencies of a number of selected solid state power supplies and major welding processes. The test results indicated significant energy savings could be achieved by: 1) substituting more energy-efficient solid state power supplies; 2) substituting less energy-intensive arc welding processes; 3) reducing energy consumption during idling. The total and distribution of energy consumption in arc welding in Ontario were estimated based on the estimated welding electrode sales in Ontario. The total electrical energy consumption in Ontario for arc welding was estimated at about 9.66×10^7 kilowatt-hours per year. The average demand during peak hours was estimated to be in the range of 28.9 to 35.1 MW.

job	file	date	report no.
81-105-812	823.111	July 25, 1991	91-150-K

91602
new 82-10

ontario hydro
research division

EXECUTIVE SUMMARY

ENERGY EFFICIENCY OPPORTUNITIES IN ARC WELDING

P.Y.Y. Maak

Ontario Hydro is interested in determining what can be done to reduce energy consumption in arc welding in Ontario, either through the selection of the most energy efficient equipment or process improvements. Arc welding is used throughout the metal fabricating and automotive industries, either as part of the production process or in a maintenance function.

This report describes an investigation into the assessment of energy efficiency opportunities in arc welding in Ontario. The project was carried out by OHRD with assistance of the Welding Institute of Canada.

An energy-efficiency testing procedure was specially designed and was used to determine the energy efficiencies of a number of selected power supplies and a number of welding processes, which account for the major portion of energy consumption in arc welding. The test results indicated that significant energy savings could be obtained by: 1) substituting high efficiency power supplies; 2) substituting less energy-intensive welding processes; 3) reducing energy consumption during idling of the power supplies. The potential areas for improvements of energy consumption in arc welding are shown in Table 1. The classification of possible energy efficiency initiatives in arc welding is shown in Table 2.

The total and distribution of energy consumption in Ontario for arc welding were estimated from welding electrode sales. The total energy consumption in Ontario for arc welding is estimated to be about 9.66×10^7 kilowatt-hours per year and takes into account energy consumption during both idling time and welding time. The percentage shares of energy consumption for shielded metal arc welding (SMAW), gas metal arc welding (GMAW), flux-cored arc welding (FCAW), and submerged arc welding (SAW) were estimated to be 65.3%, 22.9%, 7.9% and 3.9% respectively. The average demand during peak hours (8:00 am to 5:00 pm) was estimated to be in the range of 28.9 to 35.1 MW.

job	file	date	report no.
81-105-812	823.111	July 25, 1991	91-150-K

TABLE 1
SUMMARY OF POTENTIAL AREA FOR IMPROVEMENT FOR ARC WELDING

WELDING METHOD	AREA FOR IMPROVEMENT	POTENTIAL[1],[2] ENERGY SAVING	PROPORTION OF ENERGY USE IN ONTARIO BY PROCESS	POTENTIAL INDUSTRIES FOR IMPROVEMENT
1. SMAW	substitute energy efficient solid state PS	up to 79%	65.3%	On-site construction and maintenance refineries, specialty maintenance shops
	substitute energy efficient solid state PS and substitute GMAW-P	up to 87%		
	substitute gas-shielded FCAW	up to 80%		
	substitute self-shielded FCAW	up to 81%		
2. GMAW-P	select solid state PS with high energy efficiency	up to 16%	22.9% (include all GMAW process variations)	Light structural and sheet metal shops, heavy structural shops, machinery, large motor manufacturers, special maintenance shops, boiler and pressure piping manufacturers
3. Gas-shielded FCAW	substitute high energy efficient solid state PS	up to 79%	7.9%	Heavy structural shops, machinery, large motor manufacturers, boiler and pressure piping manufacturer, on-site construction and maintenance (self-shielded FCAW only)
4. Self-shielded FCAW	substitute high energy efficient solid state PS	up to 79%		
5. Single-wire SAW	substitute twin-wire SAW	up to 9%	3.9% (include all SAW process variations	Heavy structural shops, machinery, large motor manufacturer, boiler and pressure piping manufacturers.
6. All	reduce idling by improving operator factor and reduce unnecessary idling	up to 60%		All industries.

[1] The potential energy savings are estimated by the experimental studies of the present work.

[2] The energy savings described in methods 7 and 8 were estimated from the SMAW results (method 1).

TABLE 2
CLASSIFICATION OF POSSIBLE ENERGY EFFICIENCY INITIATIVES IN ARC WELDING

WELDING PROCESS	AREA FOR IMPROVEMENT	REPORT PAGE # FOR REFERENCE	POTENTIAL[1],[2] FOR IMPROVEMENT
1. SMAW	substitute energy efficient solid state PS	11, 13, 14, 35, 36, 37, 44, 45	1
	substitute energy efficient solid state PS and substitute GMAW-P	11, 12, 13, 14, 35, 36, 37, 43, 44, 45	1
	substitute gas-shielded FCAW	12, 14, 43, 44, 45	1
	substitute self-shielded FCAW	12, 14, 43, 44, 45	1
2. GMAW-P	select solid state PS with high energy efficiency	11, 12, 13, 35, 36, 37, 44, 45	2
3. GMAW-P	substitute gas-shielded or self-shielded FCAW	11, 12, 13, 35, 36, 37, 44, 45	5
4. Gas-shielded FCAW	substitute energy efficient solid state PS	11, 12, 14, 35, 36, 37, 44, 45	2
5. Self-shielded FCAW	substitute high energy efficient solid state PS	11, 12, 14, 35, 36, 37, 44, 45	2
6. Single-wire SAW	substitute twin-wire SAW	11, 12, 14, 44, 45	3
7. All	reduce idling by improving operator factor and reduce unnecessary idling	15, 44, 45	1
8. GMAW SAW	substitute narrow gap welding	16	4
9. All	reduce quantity of welding or number of weld joints through improved design engineering	3, 16	4

[1] 1 to 5 (highest to lowest)

[2] The potential for improvement was assessed based on information as shown in Table 1, Table A3 and Table A4.

TABLE OF CONTENTS

		PAGE
1.0	INTRODUCTION	1
1.1	Background and Project Objectives	2
1.2	Electrical Power and Energy Charges	
1.3	Energy Efficiency Opportunities in Arc Welding	3
2.0	ENERGY CONSUMPTION OF ARC WELDING IN ONTARIO	4
3.0	DEVELOPMENTS OF ARC WELDING TECHNOLOGY AND POWER SUPPLIES	4
3.1	Development of Solid State Power Supplies	4
3.2	Development of GMAW Technology	6
3.3	Development of FCAW Technology	6
3.4	Development of SAW Technology	7
4.0	ENERGY EFFICIENCY STUDIES FOR ARC WELDING	7
4.1	Test Methodology	7
4.2	Methods to Assess Electrical Efficiency and Energy Efficiency of Power Supplies and Welding Processes	8
4.2.1	Electrical Efficiency of Power Supplies	8
4.2.2	Energy Efficiency	9
4.3	Test Results	9
4.3.1	Specific Energy Values of Welding Electrodes	9
4.3.2	Electrical Efficiencies of Power Supplies	11
4.3.3	Energy Efficiencies	11
5.0	DISCUSSION	13
5.1	Energy Consumption and Peak Power Demand for Arc Welding in Ontario	13
5.2	Electrical Efficiency and Power Factor of Arc Welding Power Supplies	13
5.3	Energy Efficiency Opportunities in Arc Welding	14
5.4	Practicalities in the Implementation of Methods for Reducing Energy Consumption for Arc Welding	16

TABLE OF CONTENTS (Cont'd)

		PAGE
6.0 CONCLUSIONS		17
7.0 RECOMMENDATIONS		19
ACKNOWLEDGMENTS		20
REFERENCES		21
APPENDIX A	ENERGY CONSUMPTION FOR ARC WELDING IN ONTARIO	22
APPENDIX B	DESCRIPTIONS OF ARC WELDING PROCESSES	28
APPENDIX C	SOLID STATE POWER SUPPLY DESIGNS AND COMMERCIALLY AVAILABLE GMAW POWER SUPPLIES	35
APPENDIX D	ENERGY EFFICIENCY TESTING PROCEDURES AND TEST RESULTS	38
DISTRIBUTION		last page

LIST OF TABLES

		PAGE
TABLE A1	Estimation of Arc Welding Electrode Sales in Ontario from Ontario Sales Data	23
TABLE A2	Estimation of Arc Welding Electrode Sales in Ontario from USA Sales Data	24
TABLE A3	Breakdown of Electrode Sales and Energy Consumption for Various Major Arc Welding Processes in Ontario	25
TABLE A4	Breakdown of Electrode Usage By Various Industries in Ontario	26
TABLE A5	Estimated Power Demand for Arc Welding in Ontario During Peak Hours	27
TABLE B1	Overview of Joining Processes	31
TABLE C1	Solid State Power Supply Designs	35
TABLE C2	Solid State GMAW Power Supplies with Multiprocess Capabilities (Canadian Market)	36
TABLE D1	Energy-Efficiency Testing Procedure for Arc Welding	39
TABLE D2	Energy-Efficiency Test Data Sheet	40
TABLE D3	Descriptions of Welding Power Supplies and Energy-Efficiency Testing Parameters	41
TABLE D4	Specific Energy Values of Welding Electrodes	43
TABLE D5	Electrical Efficiencies and Power Consumption Data for Arc Welding Power Supplies	44
TABLE D6	Energy Consumption Data for Arc Welding	45

LIST OF FIGURES

		PAGE
FIGURE B1	Shielded Metal Arc Welding	31
FIGURE B2	Gas Metal Arc Welding	32
FIGURE B3	Gas Shielded Flux Cored Welding	33
FIGURE B4	Self Shielded Flux Cored Welding	33
FIGURE B5	Submerged Arc Welding	34

TO: Mr. J.E. Mitchell
Manager
Technical Services & Development
Program Support & Services

ENERGY EFFICIENCY OPPORTUNITIES IN ARC WELDING

P.Y.Y. Maak

1.0 INTRODUCTION

1.1 Background and Project Objectives

Currently Ontario Hydro is launching a massive campaign to encourage industries to use electrical energy more efficiently. Arc welding is a metal joining method, which is most commonly used throughout the industries as either part of the production process or in maintenance functions. In support of the Technical Services and Development Department of Program Support and Services Division, the Metallurgy Section of the Metallurgical Research Department was contracted to investigate the energy efficiency opportunities in arc welding in Ontario. This project was carried out with assistance of the Welding Institute of Canada, Oakville and the Electronics and Instrumentation Section of the Electrical Research Department.

The objectives of this project are as follows:

a) To estimate the total and distribution of energy consumption in arc welding in Ontario;

b) To review recent advances in the development of welding technology and welding equipment, which can be used to improve energy efficiency, productivity and weld quality;

c) To assess the electrical efficiencies of the arc welding processes and welding equipment, which account for the major portion of energy consumption in arc welding in Ontario;

d) To identify energy efficiency opportunities in arc welding in Ontario;

e) To recommend appropriate action plans to improve the efficiency of electrical energy usage in arc welding in Ontario.

1.2 Electrical Power and Energy Charges

Electrical power is a function of resistance and reactance, in which only the resistive component will do any useful work. Most welding power supplies have a reactive (non-resistive) power component as well as a resistive one. The reactive component of power does no real work, however, reactive power is necessary to make equipment such as motors operate. The resultant total or apparent power (kVA) is the vector sum of the real power (kW) and the reactive power (kVAR). The ratio of the portion of power that performs work (ie. the real power) to total power (ie. the apparent power) is called the power factor. Power factor is always a value between zero and one. The closer the value of the power factor to one, the better, since more of the supplied electricity will be used to perform useful work. The power factor is expressed as follows:

$$\text{power factor} = \frac{\text{real power (kW)}}{\text{apparent power (kVA)}}$$

Electrical energy is defined as the amount of work done and is generally measured in kilowatt-hours (KWH), which is the product of the real power (kW) and the time of use (in hours):

Electrical Energy (KWH) = real power (kW) x time (hour)

Although only the resistive component of the electrical power does any useful work, the reactive power component is necessary for most electrical equipment to operate. The reactive power is just as necessary as the power doing the work (ie. the resistive power). The industrial electricity users have to pay for both the resistive power and the reactive power. The amount of reactive power needed depends greatly on the how much and what kind of equipment is used by the users.

All commercial/industrial electricity bills are comprised of two components:

Energy charge + Demand Charge = Total Bill

The amount of energy charge depends on the amount of electricity consumed, which is measured in KWH. The demand charge depends on the peak power demand (kW) (ie. the maximum rate at which the customer used electricity during the billing period). In general, the power demand is measured by using watt-hour meters, which are designed to measure the amount of real power consumption over time. But in cases where it is suspected that power factor is poor (ie. less than 0.9), the utility will install (after testing) kilovolt-ampere meters, which measure both the resistive power and reactive power. The demand used for billing purposes will be the larger of the actual kW (100%) or 90% of the kVA (ie. the apparent power). This means that these customers with poor power factor will have to pay the resistive power and the reactive power. However, customers

with good power factors (ie. greater than 0.9) will only have to pay for the real power (kW).

In the present study, the effective ways that can be used to reduce electrical energy consumption and energy cost will be examined. It is perceived that energy cost can be reduced by:

a) reducing the total energy consumption (KWH) using the various methods as discussed in section 1.2, which will lead to reduction of energy charge;

b) using power supplies with improved power factors, which will reduce the demand charge.

1.3 Energy Efficiency Opportunities in Arc Welding

Based on previous energy conservation studies by others/1,2,3/, it appears that there are at least four ways or approaches, which can be applied to accomplish significant reduction in arc welding energy consumption:

Approach 1: Reduce the quantity of arc welding

- reduce the amount of deposited weld metal by using narrow gap welding techniques
- reduce the number of weld joints for a particular job through improved design
- reduce the number of weld repairs through improved welding techniques, the use of advanced welding equipment and improved quality control.

Approach 2: Substitute less energy-intensive arc welding processes

- substitute the less energy-intensive welding processes such as gas-metal-arc welding (GMAW) for other more energy-intensive welding processes such as shielded metal arc welding (SMAW).

Approach 3: Substitute more energy efficient welding power supplies

- substitute more energy efficient solid state power supplies for the less energy efficient conventional power supplies

Approach 4: Reduce idling power consumption

- minimize excessive idling time of power supplies through improved welding practices
- substitute power supplies with relatively low idling energy consumption
- add a timer or switch to existing power supplies, which will turn power off automatically to prevent unnecessarily long idling time.

2.0 ENERGY CONSUMPTION IN ARC WELDING IN ONTARIO

The total and distribution of energy consumption in Ontario were estimated using the Consumable Material Method, which is described in detail in Appendix A/1/.

As shown Appendix A, the total electrical energy consumption of arc welding in Ontario was estimated to be about 9.66×10^7 kilowatt-hours (KWH) per year. The energy consumption was estimated from the welding electrode sales of Canada (see Table A1) and the USA (see Table A2). The distribution of energy consumption by the various major welding processes is shown in Table A3. The welding processes, which account for the major portion of energy use in arc welding are as follows:

Shielded Metal Arc Welding (SMAW)
Gas-Metal-Arc Welding (GMAW)
Flux-Cored Arc Welding (FCAW)
Submerged Arc Welding (SAW)

Descriptions of the above mentioned welding processes are provided in Appendix B. Further, the relative usage of these welding processes by the industrial sectors in Ontario are shown in Table A4.

3.0 DEVELOPMENTS OF ARC WELDING TECHNOLOGY AND POWER SUPPLIES

In recent years, great advances have been made in the development of solid state power supplies, welding electrodes and welding processes for arc welding applications. These developments are driven by the need of the industries to remain competitive in the world market by increasing efficiency, including electrical efficiency, quality and productivity. It is perceived that there are at least four areas of welding developments, which may have significant impact on improving energy efficiency in arc welding:

i) Development of solid state power supplies;

ii) Development of GMAW technology;

iii) Development of FCAW technology;

iv) Development of SAW technology.

3.1 Development of Solid State Power Supplies

Most power supply designs incorporate a transformer to reduce the voltage and increase the current available for welding. The conventional systems rely on electromagnetic controls, which are robust and reliable. Although low cost equipment can be produced using this approach, the

cost of the magnetic controls devices (transformer and inductors) can increase significantly when high currents or more sophisticated control of the output are required. The availability of high power semiconductors has led to the development of a wide range of power supplies with electronic output control systems (see Table C1 in Appendix C). In comparison to the conventional power supplies, these advanced solid state power sources provide better performance, versatility and electrical efficiency. The most common designs are classified as:

- silicon-controlled rectifier (SCR)
- transistor series regulator
- transistor secondary chopper
- invertor (latest design)

In general, these advanced power supplies offer the economic and technical advantages such as:

- Versatility (multi-process capability)
- Better arc stability
- Precisely controlled output
- High electrical efficiency (ie refer only to some designs)
- Small size and lightweight (ie refer to the invertor)

Furthermore, these advanced solid state power supplies also offer the following improved welding economics:

- Increased productivity
- Improved weld quality
- Simplified interfacing with mechanized and automatic welding systems
- Single-knob control of both wire feed and power supply output

Among the various solid state power supply designs, the invertor power supply has been claimed to be the most energy efficient/4,5,6/. These studies showed that significant energy savings could be achieved by replacing conventional power supplies with the invertor power supplies. Efficient use of energy is mandated in Europe because of the high energy cost. Despite the relatively higher cost, the invertor power supplies are widely used in Europe/7/. In North America, the use of invertor power supplies is more limited since the energy cost is lower than Europe and the energy saving incentive is thus much lower. In recent years, the fabricating cost for solid state components has been decreasing considerably and it is expected the price of the invertor power supplies and other solid state power supplies will also be significantly reduced in the near future. In comparison to other conventional and solid state power supplies, the invertor power supplies excel in performance, versatility, size, weight and efficiency. The invertors are generally considered as the power supplies of the future.

3.2 Development of GMAW Technology

In the past, SMAW had always been the dominant welding process. However, in Japan and Western Europe, continuous solid wire GMAW has emerged to dominate the welding processes /8/. The survey of the present study also shows that GMAW is presently the dominant welding process in Ontario (see Table A3 in Appendix A), which is widely used in light structural and sheet metal industries (see Table A4). The use of GMAW has been increased considerably in recent years because of the need to remain competitive in the world market by increasing efficiency and hence productivity. The most significant improvement of GMAW technology is the development of solid state GMAW power supplies with multiprocess capability. There are at least 30 different designs of solid state GMAW power supplies commercially available /9/. These power supplies offer conventional GMAW, SMAW, FCAW and GTAW facilities, in addition to GMAW-P. A list of solid state GMAW power supplies, which are currently available in Canada, is shown in Table C2 of Appendix C.

For pulsed-current GMAW (GMAW-P), optimum pulsed parameters are required to produce stable spray metal transfer. In the past, the welder had to adjust the pulse parameters themselves to obtain stable metal transfer and thus a stable welding arc, which is a very difficult task. At present, the optimum pulse parameters and the relationship between the wire feed speed and frequency are preprogrammed into the solid state GMAW power supplies. Welding programs are stored inside the power supply for different wire type/wire size and shielding gas combinations. Varying the wire feed speed (and hence the mean current) automatically adjusts the pulse frequency or shape to maintain stable burn off and thus a stable welding arc. By selecting the proper weld program, the welders can establish stable welding conditions by simply choosing the required wire feed speed (ie the mean current). With the use of these advanced GMAW power supplies, a consistent stable metal transfer and welding arc could be easily obtained. GMAW-P welds can be made with good quality and higher productivity, especially in out-of position work of thinner materials.

3.3 Development of FCAW Technology

In recent years, the consumables manufacturers have made significant advances in the development of FCAW electrodes with upgraded process performance. FCAW has been used in many applications traditionally carried out using SMAW and solid wire GMAW. Small diameter wires of mild steel and low alloy steel for positional welding have been well established. Rutile based wires with good operator appeal are now formulated to achieve low temperature toughness values closely approaching that previously possible only with the basic type of electrodes. Developments in self-shielded electrodes have contributed an improvement in "welder appeal" and positional performance. The introduction of several smaller diameter wires (0.8 mm, 0.9 mm and 1.2 mm) have been found to be well suited for positional welding of thinner materials.

In comparison to SMAW and GMAW, higher weld metal deposition rates can be achieved with the use of FCAW. The slag tends to hold the weld pool in place even at high currents and deposition rates. In comparison to pulsed-current GMAW, deeper penetration and better underbead profiles can be obtained in FCAW. In comparison to GMAW-P, better quality welds with fewer fusion defects can be made using FCAW, particularly for positional welding of thick sections.

3.4 Development of SAW Technology

It is perceived that in SAW, one of the potential areas to improve energy efficiency is to replace the conventional single-wire SAW process by the twin-wire SAW process. Instead of using a single, larger wire, two smaller wires are used in twin-wire SAW. Both wires feed into the same welding pool. At the same welding current, higher deposition rates can normally be obtained in twin-wire SAW than in single-wire SAW. In the present work, energy efficiency tests were carried out to evaluate the energy efficiencies of these process variations.

4.0 ENERGY-EFFICIENCY STUDIES FOR ARC WELDING

4.1 Test Methodology

Specially designed tests were carried out to assess the energy efficiencies of a number of selected power supply designs and the following welding processes:

- shielded metal arc welding (SMAW)
- pulsed-current gas-metal-arc welding (GMAW-P)
- spray-transfer gas-metal-arc welding (GMAW)
- gas-shielded flux-cored arc welding (FCAW)
- self-shielded flux-cored arc welding (FCAW)
- single-wire submerged arc welding (SAW)
- twin-wire submerged arc welding (SAW)

The details of the testing procedures and test results are shown in Appendix D. The descriptions of power supplies under investigation and the welding parameters are shown in Table D1. The energy efficiency testing procedures and a typical test sheet are shown in Table D2 and Table D3 respectively.

In the present work, a special analyzer was used to obtain the following data:

i) real input arc-on power kW
ii) real input idling power kW
iii) power factors (arc-on and idling)
iv) apparent input arc-on power kVA
v) apparent input idling power kVA
vi) total energy consumption KWH
vii) total testing or weld time (ie. arc-on time and idling time)

A stop watch was used to record the arc-on time. The idling time was calculated from the total testing or weld time.

A weight scale with an accuracy of +/- 0.1 pound was used to weigh the test plate and the welding consumable before and after testing. The weights of the deposited weld metal and welding electrodes used were then calculated.

Meters were used to measure the output voltage and welding current, which were used to calculate the output power.

All the collected data were analyzed and used to assess the energy efficiencies of the welding power supplies and welding processes. The test results are shown in Tables D4, D5 and D6.

4.2 Methods to Assess Electrical Efficiency and Energy Efficiency of Power Supplies and Welding Processes

4.2.1 Electrical Efficiency of Power Supplies

Significant amount of incoming power (ie. input real power) can be lost in the welding power supplies. For example, in rectifier power supplies, the major energy losses are found in the transformer, reactor and rectifier. In invertor power supplies, the energy losses are mainly found in the invertor. The energy losses and thus electrical efficiencies of welding power supplies can be assessed by examining the ratios of the output power (kW) to the real input power (kW).

Many welding power supplies, which are considered as inductive loads, tend to cause the voltage and amperes to become out-of-phase. For these power supplies, the power factors (ie. the ratios of the real input power to the apparent input power) will be less than one. In this case the apparent power delivered and charged by the utility will be significantly greater than the real power, which is used for welding. This means that the industrial users will have to pay for the real power and also the excessive reactive power. In the present study, power factors are also used to assess the electrical efficiencies of the power supplies.

4.2.2 Energy Efficiency

The energy efficiencies of the power supplies and welding processes under investigation were assessed based on total energy consumption during arc time and idling time. The energy consumed is the product of the real input power and the arc (or idling) time.

Arc time is considered only while the welder is applying the weld metal. During the idling time, the welder is executing the preparation operations (eg assembling, positioning, tacking and cleaning) and follow-up operations (eg removing an assembly from a positioner, or cleaning a weld). In some cases, the power supplies are left idling while the welder is taking a coffee break or doing some other jobs. The ratio of the hours spent in welding (ie the arc time) to the total hours worked (ie the arc time and the idling time) is known as the operator factor (OF). In the present work, the OF may be defined by the equation:

$$OF = \frac{\text{Arc Time}}{\text{Arc time + Idling Time}} = \frac{\text{Arc Time}}{\text{Total Weld Time}}$$

The operator factor, which could be achieved in various welding processes, are shown as follows/10/:

SMAW (manual)	0.3
GMAW (semi-automatic)	0.5
FCAW (semi-automatic)	0.5
SAW (semi-automatic)	0.5

With the use of these operator factors, the total energy required to deposit an unit weight of weld metal were estimated for the various selected power supplies and welding processes under investigation. Furthermore, the total energy consumption under conditions of longer idling time (eg OF of 0.1 for SMAW; OF of 0.3 for GMAW, FCAW and SAW) was also estimated to evaluate the effects of excessive idling time on the energy efficiencies of the power supplies and welding processes.

4.3 Test Results

4.3.1 Specific Energy Values of Welding Electrodes

The specific energy is defined as the energy required to deposit a unit weight of weld metal or the energy required to consume a unit weight of electrodes. The specific energy values were determined for the various welding power supplies and welding processes under investigation (see Table D4).

Based on the present work, the mean specific energy values were estimated for the following types of welding electrodes:

SMAW	4.05 KWH/lb of electrodes
GMAW	1.07 KWH/lb of electrodes
FCAW	1.14 KWH/lb of electrodes
SAW	1.72 KWH/lb of electrodes

The following assumptions were made in the estimating of the above mean specific energy values:

i) SMAW

- conventional, low cost, relatively low energy efficiency power supplies (PS 1 and PS 2) represent 3/4 of SMAW used in Ontario

- state-of-the-art invertor and other higher energy efficiency power supplies (PS 3 and PS 4) represent 1/4 of SMAW power supplies used in Ontario

ii) GMAW

- advanced, highly energy efficiency solid state power supplies (ie PS 4 and PS 5) represent 1/3 of the power supplies used in GMAW applications in Ontario (refer to pulsed current and short circuiting GMAW)

- conventional solid state rectifier power supply (PS 6) represents 2/3 of the power supplies used in GMAW applications in Ontario (refer to high current spray-transfer GMAW)

iii) FCAW

- the SCR rectifier power supply (PS 6) represents the typical power supplies in FCAW applications in Ontario

- gas-shielded FCAW and self-shielded FCAW have an equal share of usage in Ontario

iv) SAW

- single wire SAW represents the dominant SAW technique used in Ontario

The mean specific energy value of the welding electrodes were used in Section 2 to calculate the total and distribution of energy consumption in Ontario (see Table A3)

4.3.2 Electrical Efficiencies of Power Supplies

The electrical efficiencies (ie. based on the ratio of the output power to the real input power) of the various power supplies and welding processes under investigation (shown in Table D5), were found to range from 18.5 to 89.9%. The descriptions of power supplies and welding parameters used are shown in Table D3.

In the SMAW tests, PS 1 and PS 2, which represent conventional, low cost rectifier power supplies, were found to have low electrical efficiencies of 18.5 and 34.6% respectively. PS 3 and PS 4, state-of-the-art invertor power supplies, were found to have considerably higher electrical efficiencies of 89.9% and 80.0% respectively.

In the GMAW tests, PS 5 (ie a transistorized power supply) was found to have electrical efficiency of 72.7%, which was higher than the measured electrical efficiency (63.6%) of PS 4 (an invertor power supply).

In the GMAW, FCAW and SAW tests, the electrical efficiencies of the rectifier power supplies tested were found to have efficiencies ranging from 63.0% to 81.6%.

As shown in Table D5, PS 2 and PS 3 had excellent power factors of 0.98 and 0.99 respectively. Other power supplies such as PS 1, PS 4, PS 5, PS 6 and PS 7 had power factors that ranged from 0.4 to 0.74. For these power supplies with poor power factors, the apparent power delivered by the utility was much higher than the real power required for welding (see Table D5).

4.3.3 Energy Efficiencies

The total energy values per unit weight of deposited weld metal are shown in Table D6. These data were used to evaluate and compare the energy efficiencies of the various power supplies and welding processes under investigation.

Shielded-Metal-Arc Welding (SMAW)

As shown in Table D6, the invertor power supplies (PS 3 and PS 4) had significantly higher energy efficiencies than the conventional rectifiers (PS 1 and PS 2). These invertors consumed considerably less energy during arc time and idling time. With an operator factor of 0.3, the present test results indicated that energy savings ranged from 60% to 78% could be achieved by replacing the less energy efficient power supplies (ie PS 1 and PS 2) with the highly energy efficient power supplies (ie PS 3 and PS 4).

The present results appeared to show that the energy efficiencies of the power supplies depended greatly on the operator factor used (ie the ratio of arc time to total weld time), particularly for those power supplies which consumed a great deal of energy during idling. With an operator factor of 0.3, PS 1 and PS 2 showed comparable energy efficiencies. With an operator factor of 0.1 (ie idling time represents 90% of the total weld time), PS 1, which consumed less energy during idling, became more energy efficient than PS 2.

PS 3 and PS 4 are both invertor power supplies. With an operator factor of 0.3, PS 3 consumed only about 68% of the total energy required by PS 4.

Pulsed-Current Gas-Metal-Arc Welding (GMAW-P)

An invertor power supply (PS 4) and a transistorized power supply (PS 5) were used in the GMAW-P studies. With an operator factor of 0.5, PS 5 consumed only about 84% of the energy required by PS 4.

The present work showed that GMAW-P (ie with the use of PS 3 and PS 4) only required about 13% to 20% of the energy required by SMAW (ie with the use of PS 1 and PS 2).

Gas-Metal-Arc-Welding (GMAW)

PS 6, which is a conventional rectifier power supply, was used in the high current GMAW studies. It was shown that GMAW (ie with the use of PS 6) required only about 18% to 23% of the energy required by SMAW (ie with use of PS 1 and PS 2).

Gas-Shielded Flux-Cored Arc Welding (FCAW)

It was shown that gas-shielded FCAW (ie with PS 6) only required about 20% to 26% of the energy required by SMAW (ie with PS 1 and PS 2).

Self-Shielded Flux-Cored Arc Welding (FCAW)

With an operator factor of 0.3, it was shown that self-shielded FCAW (ie with PS 6) only required about 19% to 24% of the energy required by SMAW (ie with PS 1 and PS 2).

Submerged Arc Welding (SAW)

Two parallel-connected rectifier power supplies (ie PS 7) were used in the single-wire SAW and twin-wire SAW studies. The present work indicated that twin-wire SAW required about 91% of the energy required by single-wire SAW.

5.0 DISCUSSION

5.1 Energy Consumption and Peak Power Demand for Arc Welding in Ontario

As a result of this report, the reader should now have a better understanding of the type of arc welding processes and their applications (Tables 1, A4 and B1). The efficiencies of various types of power supplies (Tables D5 and D6) and the energy consumed by each of the processes (Table A3). This report did not attempt to identify the specific type of equipment (design) used by each industry. Only the welding processes used by each industry were identified and the options available to improve energy efficiency were discussed.

In the present work, the total annual consumption for arc welding in Ontario was estimated to be about 9.66×10^7 KWH using the Consumable Materials Method. In addition to the energy consumption during welding, the energy consumption when the arc was off had also been taken into consideration in the present work. The ratio of arc time to total power supply on-time was estimated to be 0.3 (70%) for SMAW, 0.5 (50%) for GMAW, FCAW and SAW. However, it was estimated in previous studies/1/ that the ratio of arc time to total power supply-on time was probably less than 0.2 (20%) for most welding. This means that more energy was probably wasted during idling in reality. The electrical energy actually used annually in Ontario for arc welding is probably much higher the present estimated 9.66×10^7 KWH.

The power demand for arc welding in Ontario during peak working hours (ie 8:00 am to 5:00 pm) was estimated to be in the range of 28.9 to 35.1 MW (see Table A5 in Appendix A). This is based on the assumption that 70% to 85% of all the arc welding applications in Ontario are carried out during the above mentioned day-time working hours.

5.2 Electrical Efficiency and Power Factor of Arc Welding Power Supplies

As shown in Table D5, the electrical efficiencies (ie. ratio of the output power to the real input power) were estimated to be in the range of 18.5% to 89.9%. These results indicated that a high percentage of real input power were lost in the power supplies.

The SMAW test results showed that the invertor power supplies had much higher electrical efficiencies than the conventional low cost rectifier power supplies. The test results indicate that more than 81% of real input power could be lost in the rectifier power supplies (see Table D5). For the invertor power supplies, the percentage loss of real input power could be as low as 10 percent.

The GMAW-P test results indicated that the electrical efficiency of the invertor PS 5 (72.7%) was found to be higher than the electrical efficiency of the invertor PS 4 (63.6%). In PS 4, a step-down transformer was used to transform the incoming voltage of 575 volts to the acceptable 460 volts. The present work showed that the step-down transformer accounted for an additional loss of 5% to 6% of the real input power.

In the GMAW, FCAW and SAW tests, the electrical efficiencies of the SCR rectifier power supplies tested were found to have electrical efficiencies ranging from 63.0% to 81.6%.

As shown in Table D5, the power factors of the low cost rectifier power supplies (ie. PS 1, PS 6 and PS 7) were found to have poor power factors in the range of 0.4 and 0.74. PS 2 had, however, an excellent power factor of 0.98.

It was found that PS 3 (an invertor power supply) and PS 5 (a transistorized power supply) had excellent power factors of 0.99 and 0.97 respectively. However, PS 3 (a different design of invertor power supply) had a poor power factor of about 0.60.

As discussed in section 1.2, industrial electricity users with poor power factors (ie. less than 0.9) will be charged for 90% of the kVA (ie. the apparent power), which will be higher than the real power kW. The present work showed that different power supply designs, including low cost rectifier power supplies and advanced transistorized/invertor power supplies, might have a wide range of power factors (0.4 to 0.99). The selection of power supplies with poor power factors might worsen the power factor of the entire industrial plant, which will lead to significant increase in the demand charge or higher installation cost of capacitors (ie. to improve the power factor of the plant).

5.3 Energy Efficiency Opportunities in Arc Welding

i) Substitute Energy-Efficient Solid State Power Supplies and Less Energy-Intensive Welding Processes

Based on the present investigation, a summary of potential areas for improvement of energy consumption in arc welding was prepared (see Table 1). The classification of all the possible energy initiatives in arc welding is shown in Table 2. The potential areas can be categorized as follows:

The present investigation appeared to indicate that energy savings up to 79% (see Table 1) can be achieved by substituting energy efficient solid state power supplies (with multi-process capability - SMAW, GMAW and FCAW) for inefficient conventional power supplies. These advanced power supplies offer the industrial user greater versatility in the choice of welding processes that they can use.

The present investigation showed that SMAW accounts for more than 65% of the total energy consumption for arc welding in Ontario. Because of the availability of the multiprocess capability the industrial users, who are currently using SMAW, can select to remain using SMAW in their welding operations. With advanced electronic output controls, more stable and controllable welding conditions could be obtained using the advanced power supplies. High quality welds could likely be made with fewer defects, which would lead to lower labour and energy cost. In this case, there is no need for requalifying the existing welding procedures or retraining welders. These industrial users may also select to use continuous wire welding

processes such as GMAW (ie GMAW-P and GMAW-S) and FCAW. It was shown in the present work that energy savings up to 87% could be obtained by replacing SMAW with semi-automatic GMAW and FCAW (see Table 1). Other advantages are significantly improved productivity and weld quality, which would considerably reduce the labour cost. In this approach, it is necessary to qualify new GMAW and FCAW procedures. Furthermore, the welder may also need some training to become familiarized with the GMAW and FCAW techniques. It was shown in previous studies that welders, who were unfamiliar with both the solid state power supplies and the continuous wire welding processes, could weld competently with minimum training in a very short period of time/11/.

ii) Reduce Energy Consumption During Idling of Power Supplies

It was found in the present investigation that the rectifier power supplies (ie with saturable reactor and SCR as primary output control) required very high input idling power (ie up to 4.81 kW). It was shown that energy savings up to 60% could be achieved by reducing the idling energy consumption (see Table 1). Three methods have been identified for reduction of idling energy consumption in arc welding:

a) use power supplies requiring lower idling power

b) educate the industrial user to improve the energy efficiencies of their operations by increasing the ratio of the arc time to the total power supply-on time (ie reduce the unnecessary idling time).

c) add a timer or switch to the existing power supplies (ie to automatically shut off the power after a certain period of time following the welding task)

iii) Employ A More Energy-Efficient Process Variation

It was shown in the present work that energy savings up to 9% could be achieved by replacing single-wire SAW with the twin-wire SAW process.

iv) Other Methods for Reducing of Energy Consumption in Arc Welding

a) Higher Weld Metal Deposition Rate: It was shown in previous studies that a higher weld metal deposition rate and thus higher productivity could be obtained by replacing the GMAW with the gas-shielded FCAW or the self- shielded FCAW/11/. However, the present work indicated that FCAW processes are much more energy-intensive than GMAW. Replacing GMAW with FCAW may lead to improved productivity and weld quality, but would not offer any energy saving opportunities.

b) Narrow Gap Techniques: Great advances have been made in recent years in the development of narrow-gap GMAW and SAW techniques and equipment/12,13/. In comparison to conventional techniques, the narrow gap welding techniques improve the productivity significantly (ie, particularly for thick materials) by reducing the amount of deposited weld metal, which would also lead to considerable energy savings. Other advantages include improvements in joint toughness, weld quality and a reduction in welding deformation. However, narrow gap welding requires the need for an advancement in welding skill and the capital equipment cost is higher. Furthermore, it is very difficult to repair narrow-gap welds. It is perceived that considerable amount of energy savings could be obtained by using the narrow gap welding techniques.

5.4 Practicalities in the Implementation of Methods for Reducing of Energy Consumption for Arc Welding

It is apparent from the present investigation that significant amount of energy savings could be achieved in arc welding by using the energy-efficient improvement methods as listed in Table 1. It is also important to realize that the cost of energy for arc welding alone for any plant is not typically a major expense. It is frequently very difficult for the plant manager or operations manager to make any significant changes in processes, practices or equipment on the basis of payback or return-of-investment from the values of the energy saved. The other factors such as the welder's time (labour cost), productivity, product quality and training requirements for welders must also be carefully evaluated.

As mentioned previously, there are at least 30 commercially available solid state power supplies with multi-process capability. These power supplies differ from each other in terms of energy efficiency and welding characteristics. The invertor power supplies are generally considered to be the most energy efficient solid state power supply designs. The present investigation had, however, shown that this may not true. One of the invertor power supplies tested appeared to be less energy efficient than the transistorized power supply tested. The power factors of the invertor and transistorized power supplies were also found to range from 0.58 to 0.99. The present investigation appears to indicate that further studies are required to characterize the advanced solid state power supplies (ie commercially available in the Canadian market) in terms of energy efficiency, power factor and performance. This information will be useful for the Ontario industries in the selection of the most suitable power supplies for their welding applications.

In order to promote the usage of energy-efficiency improvement methods for arc welding, Ontario Hydro must provide Ontario industry with an information package, which includes the following information:

a) potential areas for reductions in energy consumption for arc welding;

b) potential savings in energy cost;

c) a list of recommended solid state power supplies, including a brief review of the energy efficiencies, performance of these power supplies and associated equipment cost;

d) training requirements for welders;

e) potential benefits such as improved productivity and weld quality.

6.0 CONCLUSIONS

The current investigation presents an overall picture of energy consumption for arc welding in Ontario, including the total energy consumption, the peak power demand, proportion of energy consumption by industry, proportion of energy consumption by welding process, energy efficiencies of major welding processes and various types of solid state power supplies, and energy efficiency opportunities in arc welding. The following conclusions are drawn from the present work:

6.1 The total energy consumption in arc welding in Ontario is estimated to be about 9.66 x 10^7 kilowatt-hours.

6.2 The percentage shares of energy consumption by SMAW, GMAW, FCAW and SAW are estimated to be 65.3%, 22.9%, 7.9% and 3.9% respectively.

6.3 The demand during peak hours for arc welding in Ontario is estimated to be in the range of 28.9 to 35.1 MW (ie based on the assumption that 70% to 85% of all the arc welding applications are carried out during the daytime working hours from 8:00 am to 5:00 pm).

6.4 The values of specific energy of electrodes for SMAW, GMAW, FCAW and SAW have been estimated to be 4.05, 1.07, 1.14 and 1.72 KWH/lb. These results appear to indicate that GMAW is the least energy-intensive welding process.

6.5 Energy savings up to 60% can be obtained by improving the ratio of the arc time to the power supply-on time (ie to reduce the amount of unnecessary idling time).

6.6 Energy savings up to 79% in SMAW could be obtained by substituting energy efficient power supplies.

6.7 Energy savings up to 87% can be obtained by replacing SMAW (low efficiency) with GMAW-P (high efficiency) power supplies.

6.8 Energy savings up to 81% can be obtained by replacing SMAW with gas-shielded or self-shielded FCAW.

6.9 Energy savings up to 9% can be obtained by replacing single-wire SAW with twin-wire SAW.

6.10 Besides providing energy saving opportunities, the use of solid state power supplies with multiprocess capability also offer other benefits such as greater versatility, improved productivity and weld quality, which could lead to a reduction of labour cost.

6.11 Invertor power supply designs are generally considered to be the most energy efficient solid state power supply designs. However, the other power supply designs such as transistorized power supplies, may be more energy efficient than some invertor power supplies. The energy efficiencies of solid state power supplies from different manufacturers must, therefore, be assessed separately.

6.12 The electrical efficiencies (ie. the ratio of the output power to the real input power) of the power supplies under study are in the range of 18.5% to 89.9%. The transformer-rectifier power supply can lose as much as 81.5% of the real input power. The losses of real input power in invertor power supplies can be as low as 10.1%.

6.13 The power factors (ie. the ratio of real input power to the apparent input power) of the power supplies under study are found to be in the range of 0.4 to 0.99. The test results indicate that the power factors of power supplies from different manufacturers must, therefore be assessed separately.

6.14 The selection of power supplies with poor power factors (ie. less than 0.9) will worsen the power factor of the industrial plant, which will lead either to an increase of the demand charge or higher installation cost of capacitors (ie. to improve the power factor of the plant).

6.15 The energy cost of arc welding alone for any industrial plant is not typically a major expense. Before the plant manager decides to make any significant changes, he must consider the value of energy saved and, more importantly, other factors such as improvements to productivity (ie labour cost), improved weld quality, equipment cost and required welder training.

7.0 RECOMMENDATIONS

In order to promote the usage of energy-efficient methods as described in this report, the following action plans are recommended:

i) Organize workshops

- provide the users with information on energy efficiency opportunities in arc welding
- provide the users with information on Ontario Hydro's energy incentive program
- obtain feedback from the industry

ii) Assessment of Commercially Available Solid State Power Supplies (By Manufacturer)

- evaluate the energy efficiencies and the performance of commercially available solid power supplies (by manufacturer) (a number of power supply distributors have already indicated their interest in the energy incentive program and are willing to provide their power supplies to Ontario Hydro for evaluation at no cost)

- establish a data base on commercially available solid state power supplies (by manufacturer), which could be used as a reference by the industries and Ontario Hydro in the selection of appropriate power supplies

iii) Assessment of Methods for Reduction of Idling Power

- evaluate the practicality of reducing idling power consumption by controlling the idling time using a timer or a switch

- establish the most appropriate method for controlling the idling time

ACKNOWLEDGEMENT

The author wishes to express his thanks to the Welding Institute of Canada in general and to Mr. B. Bryan and Mr. B. Spahr in particular for collecting electrode sales data and process usage data for Ontario and for performing most of the welding tests. Thanks are also extended to Mr. G.L. Grant of the Electrical Research Department for performing all the electrical energy consumption measurements. The author also would like to thank Mr. J. Galloway for carrying out welding tests at OHRD and his assistance in the preparation of this report. Thanks are also given to the Technical Services and Development Department for supporting this project and to Mr. B.P. O'Rourke in particular for useful discussions and review of this report. The author would also like to acknowledge Dr. W.H.S. Lawson and Mr. P. Labaj of the Electrical Research Department for their technical review of this report.

Recommended by:

W.H.S. Lawson
Supervising Engineer
Metallurgy Section

Prepared by:

P.Y.Y. Maak
Engineer-Welding
Metallurgy Section

Approved by:

J.Brown
Manager
Metallurgical Research Dept

REFERENCES

1. Smartt, H.B. et. al., "Welding Industry: Potentials for Energy Conservation", EGG-2027, U.S. Department of Energy, April, 1980.

2. Cyclomatic Industries Inc., "Industry Testing of Highly Efficient Arc-Welding Power Supply", DOE/CS/40332-T1, U.S. Department of Energy, September, 1982.

3. Bradburn, F. and Donaldson, A., "Highly Efficient Arc Welding Power Supply", Proc. Intersociety Energy Conversion Engineering Conference, Aug. 1982.

4. Schiedermayer. M., "The Invertor Power Supply", Welding Design & Fabricator, June, 1987.

5. 4 Shira, C., "Convertor Power Supplies - More Options for Arc Welding", Welding & Fabricator, June, 1985.

6. Strazisar, F., "Exploring Application Economics of Welding Invertors", The Fabricator, Vol. 21, No. 2, March, 1991.

7. Cullison, A., "Changes Are Coming for Welding Power Supplies", Welding Journal, May, 1990.

8. Taylor, D.S., "The Role of MMA Welding In the 1990", Welding & Metal Fabrication, May, 1990.

9. Harris, I., "Pulse MIG/MAG Welding", Joining & Materials, June, 1989.

10. Twelfth Edition, The Procedure Handbook of Arc Welding, The Lincoln Electric Company, Cleveland, Ohio, June 1973.

11. Mathers, G., "A fabricator's View of Synergic MIG Welding", Joining & Materials, June, 1989.

12. Ellis, D.J., "Mechanised Narrow Gap Welding of Ferritic Steel", Joining & Materials, August, 1988.

13. Matsuda, F. and Masumoto, I., "Narrow Gap Welding - The State-of-the-Art in Japan", International Institute of Welding Document IIW XII-961-1986, 1986.

APPENDIX A

ENERGY CONSUMPTION FOR ARC WELDING IN ONTARIO

The Consumable Materials Method which was used in the present investigation to estimate the total and distribution of energy consumed in arc welding in Ontario, is described as follows:

Estimation of Welding Consumable (Electrode) Sales in Ontario

Because of the unavailability of welding electrode sales data for Ontario, the electrode sales in Ontario were estimated using the electrode sales data from Canada and the USA (see Tables A1 and A2). The total sales of welding electrodes in Ontario in 1986 were estimated to be about 19,504 tons (ie based on 1986 Canada sales data - see Table A1) and 20,250 tons (ie based on 1986 USA sale data - see Table A2). The results were found to be comparable, indicating that both the "Canada" and "USA" methods could be used to estimate the Ontario electrode sales. Based on the 1989 USA data (ie the most up-to-date data), the total Ontario electrode sales were estimated to be about 22,350 tons (ie about 10% higher than the 1986 estimated sales). Because of the relatively slow growth of the economy in Ontario in recent years, it has been suggested that the present electrode sales in Ontario should not be significantly different from the estimated 1989 sales. For the present study, the estimated 1989 sales of 22,350 tons were, therefore, used to estimate the present energy consumption in arc welding in Ontario.

Energy Consumption in Arc Welding in Ontario

The relative sales of welding electrodes for the major welding processes in Ontario, which were provided by the welding electrode distributors, are shown in Table A3. The energy consumption by various major welding processes in Ontario were then estimated from the consumable sales (see Table A4). The total energy consumption is estimated at 9.66×10^7 KWH. The breakdown of electrode usage by various industries in Ontario is shown in Table A4.

TABLE A1
ESTIMATION OF ARC WELDING ELECTRODE SALES IN ONTARIO FROM ONTARIO SALE DATA

Estimation of Reduction Factor

1. Using Ontario/Canada Populations* as a Reduction Factor

   (9,431,000/25,871,000 --- 0.36)

2. Using Ontario/Canada Gross Domestic Products for 1989** as a Reduction Factor

   ($269,997,000,000/$650,904,000,000 --- 0.4)

3. Using Ontario/Canada Value of Fabricated Metal Product Shipments for 1987*** as a Reduction Factor

   ($11,235,012,000/$1,786,392,000 --- 0.63)

The average reduction factor is about 0.46.

Estimation of Arc Weld Electrode Sales in Ontario

Total 1986 Arc Welding Electrode Sales in Canada = 42,400 tons

Estimated 1986 Arc Welding Electrode Sales in Ontario = 42,400 tons x 0.46

= 19,504 tons

* Canada Year Book 1990

** Canadian Economic Observer January 1991 Section 12.1

Gross Domestic Product

The unduplicated value of production originating within the geographic boundaries, regardless of whether the factors of production are Canadian or non-resident.

*** Statistics Canada Catalogue 31-203 Annual 1987 Manufacturing Industries of Canada: National Provincial Areas: Principal Statistics by Major Group and Industry: Fabricated Metal Products

TABLE A2
ESTIMATION OF ARC WELDING ELECTRODE SALES IN ONTARIO FROM USA SALES DATA

Estimation of Reduction Factor

1. Using Ontario/USA Populations* as a Reduction Factor

   (9,431,000 / 250,000,000 --- 0.04)

2. Using Ontario/USA Gross Domestic Products for 1989** as a Reduction Factor

   ($269,997,000,000 / $5,307,854,500,000** --- 0.05)

   The average reduction factor is about 0.045.

Estimation of Arc Welding Electrode Sales in Ontario

Total 1986 Arc Welding Electrode Sales in USA =	450,000 tons
Estimated 1986 Arc Welding Electrode Sales in Ontario =	450,000 tons x 0.045 = 20,250 tons

(The 1986 Sales of 19,504 tons estimated from the Canadian sales data is about 37% lower than the 1986 sales of 20,250 tons estimated from the USA sales data).

Total 1989 Arc Welding Electrode Sales in USA =	496,667 tons
Estimated 1989 Arc Welding Electrode Sales in Ontario =	496,667 tons x 0.045
	22,350 tons

* The World Almanac and Book of Facts 1991

** Canadian Economic Observer January 1991 Section 13.1. Figure given in 1982 US dollars has been adjusted for inflation.

TABLE A3
BREAKDOWN OF ELECTRODE SALES AND ENERGY CONSUMPTION FOR VARIOUS MAJOR ARC WELDING PROCESSES IN ONTARIO

Process	% Share[3] of Sales by weight	Estimated[4] Sales lb	Specific Energy[5] for Welding Consumable KWH/lb	Energy Consumption KWH	% Share of Energy Consumption
SMAW	35	1.56×10^7	4.05	6.31×10^7	65.3%
GMAW	45	2.07×10^7	1.07	2.21×10^7	22.9%
FCAW	15	0.67×10^7	1.14	0.76×10^7	7.9%
SAW	5	0.22×10^7	1.72	0.38×10^7	3.9%
				9.66×10^7	100%

[3] information supplied by local distributors of welding electrodes in Ontario

[4] total sales are estimated at about 22350 tons or 4.47×10^7 lbs (see Table A2)

[5] values of specific energy obtained the present work (see Table D4 in Appendix D)

TABLE A4
BREAKDOWN OF ELECTRODE USAGE BY VARIOUS INDUSTRIES IN ONTARIO

	SMAW	GMAW	FCAW	SAW
Heavy Structural Shops	5%	15%	60%	20%
Light Structural and Sheet Metal Shops	5%	95%		
Machinery, Large Motor Manufacturers	5%	25%	60%	10%
Specialty Maintenance Shops for Hardfacing, Customized One-Offs, etc	80%	20%		
On-site Construction and Maintenance	80%		20%	
Boiler and Pressure Piping Manufacturers	10%	15%	5%	70%
Refineries	100%			

TABLE A5

ESTIMATED POWER DEMAND FOR ARC WELDING IN ONTARIO DURING PEAK HOURS

Assumptions

i. 70 to 85% of the total arc welding applications in Ontario are performed during the nine (9) day-time peak working hours (ie 8:00 am to 5:00 pm).

ii. There are 5 working days per week and 52 working weeks per year.

iii. Total annual energy consumption for arc welding in Ontario is 9.66×10^7 kilowatt hours.

iv. Total day-time peak working hours = 9 x 5 x 52 = 2340 hours.

Peak Power Demand (Based on 70% of arc welding applications) $= \frac{9.66 \times 10^7 \times 0.7}{2340} = 28.9 \times 10^3$ kilowatt $= 28.9$ MW

Peak Power Demand (Based on 85% of arc welding applications) $= \frac{9.66 \times 10^7 \times 0.85}{2340} = 35.1 \times 10^3$ kilowatt $= 35.1$ MW

* The assumptions were made based on the author's personal view and no data were collected to justify these assumptions.

* Also, since the majority of power supplies in current use have power factors significantly less than 1.0, it should be noted that the gross electrical demand in MVA associated with welding operations will be significantly greater than the above figures in MW.

APPENDIX B

DESCRIPTIONS OF ARC WELDING PROCESSES

An overview of joining processes is shown in Table B1. The arc welding processes, which account for the major portion of energy consumption in arc welding, are described as follows:

Shielded Metal Arc Welding (SMAW)

The SMAW is a manual arc welding process, which has wide applications in the construction, pipeline, and maintenance industries. It is a simple and versatile welding process. The SMAW process is illustrated in Figure B1. It uses a covered electrode consisting of a core wire and a concentric clay-like covering. This covering is a source of arc stabilizer, gases to displace air, slag to protect, support and insulate the hot weld metal.

The SMAW has several advantages. Using the SMAW, job shops can handle many welding applications. Other advantages are the simplicity and lightness of the equipment, and its relative low cost. Also welds can be made in confined locations or remote from heavy power supplies.

The main disadvantage of the SMAW is its low productivity and high labour cost. Cleaning of the slag covering from the weld bead is required after each weld pass. Frequent discarding of electrode stubs for new electrodes is also needed.

Gas-Metal-Arc Welding (GMAW)

The GMAW is a continuous wire welding process, which is illustrated in Figure B2. The electrode is solid and all the shielding gas is supplied from an external source. Welders can weld continuously with GMAW since the wire is fed continuously and only fatigue or changing position requires the arc to be interrupted. There is no need to remove slag covering between weld passes.

In GMAW, there are three different modes of metal transfer across the arc, which are known as spray, globular and short- circuiting. Spray transfer and globular transfer require high welding currents while short-circuiting transfer commonly uses low average current.

In the spray transfer GMAW process variation, argon or argon-rich shielding gas mixtures are used to shield the arc and welding zone. Small discrete droplets of metal are transferred across the arc. The amperage must be above a critical value related to the electrode diameter. The metal transfer is very stable, directional and spatter free. However, high current spray transfer GMAW limits its effective use for joining thin sheet metal and for welding in the vertical and overhead positions. It is used extensively for flat position welding. Pulsed-current gas-metal-arc welding (GMAW-P) can be used to acquire spray transfer at low average currents. When intermittent, high amplitude pulses of welding current are superimposed on a low level of background current that maintains the arc, the average current can be reduced appreciably. Spray metal transfer can

thus be achieved at low average currents. Pulsed arc operation is produced by the utilization of a programmed power supply. The GMAW-P can be used to weld thin as well as thick sections of metals in all positions. However, lack-of-fusion can be a problem in all position thick-section welding.

In the globular GMAW process variation, carbon dioxide-rich gases are used to shield the welding arc and the welding zone. The filler metal transfers across the arc in globules propelled by arc forces. Considerable spatter is produced. The welding arc is, however, more penetrating. Carbon dioxide is reactive, and is used only for steels which can be properly alloyed to tolerate an oxidizing atmosphere and for steels that do not require very low carbon content.

The short-circuiting GMAW process variation (GMAW-S) is primarily used for welding thin sections and out-of-position joints. With the short-circuiting mode, the welding current and deposition rate are limited by using power supplies, which allow metal to be transferred across the arc only during intervals of control short circuits. However, incomplete fusion can be a problem when welding of sections thicker than 6.5 mm (1/4 inch).

Flux-cored Arc Welding (FCAW)

The FCAW process uses cored electrodes. The process is illustrated in Figure B3. The flux core may contain minerals, ferroalloys, deoxidizers, slag forming materials and materials that provide shielding gases. For gas shielded FCAW, external gas shielding is required to provide additional shielding. For self-shielded FCAW, no external gas shielding is required. The self-shielded FCAW electrodes are designed to generate protective shielding gases from additions in the cored materials, similar to SMAW.

In comparison to SMAW or solid wire GMAW, FCAW provides higher deposition rates. The weld pool is protected and supported by the slag covering. For all-position welding applications, higher welding current and thus higher weld metal deposition rates can be achieved in FCAW than in solid wire GMAW. In comparison to gas-shielded FCAW, the self-shielded FCAW is more tolerable to draft and is preferred for site welding and other outdoor work.

The FCAW is a more forgiving welding process than gas-metal-arc welding. However, FCAW tends to generate considerable amount of welding fumes and excellent ventilation is required for in-door welding applications.

Submerged Arc Welding (SAW)

In SAW, the arc and the molten weld pool are shielded by an envelop of molten flux and a layer of unfused granular flux particles as shown in Figure B4. The welding arc is not visible during welding. Very little fumes are produced in SAW.

Among all the arc welding processes, SAW produces the highest metal deposition rate. However, welds can only be made in the flat and horizontal welding positions.

There are several process variations in SAW. The single wire SAW is the most commonly used variation. Other variations include twin-wire SAW and tandem wire SAW.

TABLE B1
OVERVIEW OF JOINING PROCESSES

Material	Thickness	Joining Process**																						
		SMAW	SAW	GMAW	FCAW	GTAW	PAW	ESW	EGW	RW	FW	OFW	DFW	FRW	EBW	LBW	B							S
																	TB	FB	IB	RB	DB	IRB	DFB	
Carbon Steel	S	X	X	X		X				X	X	X			X	X	X	X	X	X	X	X	X	X
	I	X	X	X	X	X				X	X	X		X	X	X	X	X	X	X	X		X	X
	M	X	X	X	X					X	X	X		X	X	X	X	X	X				X	
	T	X	X	X	X			X	X		X	X		X	X			X					X	
Low Alloy Steel	S	X	X	X		X				X	X	X			X	X	X	X	X	X	X	X	X	X
	I	X	X	X	X	X				X	X		X	X	X	X	X	X	X				X	X
	M	X	X	X	X						X		X	X	X		X	X	X				X	
	T	X	X	X	X			X		X	X		X	X	X		X	X				X		
Stainless Steel	S	X	X	X		X	X			X	X	X			X	X	X	X	X	X	X	X	X	X
	I	X	X	X	X	X	X			X	X		X	X	X	X	X	X	X				X	X
	M	X	X	X	X		X				X		X	X	X	X	X	X	X				X	
	T	X	X	X	X			X			X		X	X	X			X					X	
Cast Iron	I	X										X					X	X	X				X	X
	M	X	X	X	X							X					X	X	X				X	X
	T	X	X	X	X							X						X					X	
Nickel and Alloys	S	X		X		X	X			X	X	X			X	X	X	X	X	X	X	X	X	X
	I	X	X	X		X	X			X	X			X	X	X	X	X	X				X	X
	M	X	X	X			X				X			X	X	X	X	X	X				X	
	T	X		X				X			X			X	X			X					X	
Aluminum and Alloys	S	X		X		X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	I	X		X		X				X	X		X	X	X	X	X	X	X				X	X
	M	X		X		X					X			X	X		X	X	X				X	
	T	X		X				X	X		X			X	X			X					X	
Titanium and Alloys	S			X		X	X			X	X		X		X	X			X	X		X	X	
	I			X		X	X				X		X	X	X	X		X	X				X	
	M			X		X	X				X		X	X	X	X		X	X				X	
	T			X							X		X	X	X		X	X					X	
Copper and Alloys	S			X		X	X				X				X		X	X	X	X			X	X
	I			X			X				X			X	X		X	X		X			X	X
	M			X							X			X	X		X	X					X	
	T			X							X				X			X					X	
Magnesium and Alloys	S			X		X				X					X	X	X	X			X		X	
	I			X		X				X	X			X	X	X	X	X			X		X	
	M			X							X			X	X	X		X					X	
	T			X							X				X									
Refractory Alloys	S			X		X	X			X	X				X		X	X	X	X		X	X	
	I			X			X				X				X		X	X					X	
	M									X	X													
	T																							

*This table presented as a general survey only. In selecting processes to be used with specific alloys, the reader should refer to other appropriate sources of information.
**See legend below.

LEGEND

Process Code

SMAW—Shielded Metal Arc Welding
SAW—Submerged Arc Welding
GMAW—Gas Metal Arc Welding
FCAW—Flux Cored Arc Welding
GTAW—Gas Tungsten Arc Welding
PAW—Plasma Arc Welding
ESW—Electroslag Welding
EGW—Electrogas Welding
RW—Resistance Welding
FW—Flash Welding
OFW—Oxyfuel Gas Welding
DFW—Diffusion Welding
FRW—Friction Welding
EBW—Electron Beam Welding
LBW—Laser Beam Welding
B—Brazing
TB—Torch Brazing
FB—Furnace Brazing
IB—Induction Brazing
RB—Resistance Brazing
DB—Dip Brazing
IRB—Infrared Brazing
DFB—Diffusion Brazing
S—Soldering

Thickness

S—Sheet: up to 3 mm (1/8 in.)
I—Intermediate: 3 to 6 mm (1/8 to 3/4 in.)
M—Medium: 6 to 19 mm (1/4 to 3/4 in.)
T—Thick: 19 mm (3/4 in.) and up

X—Commercial Process

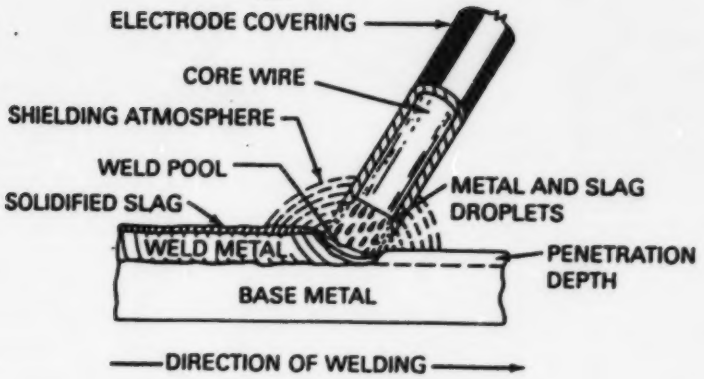

FIGURE B1

SHIELDED METAL ARC WELDING

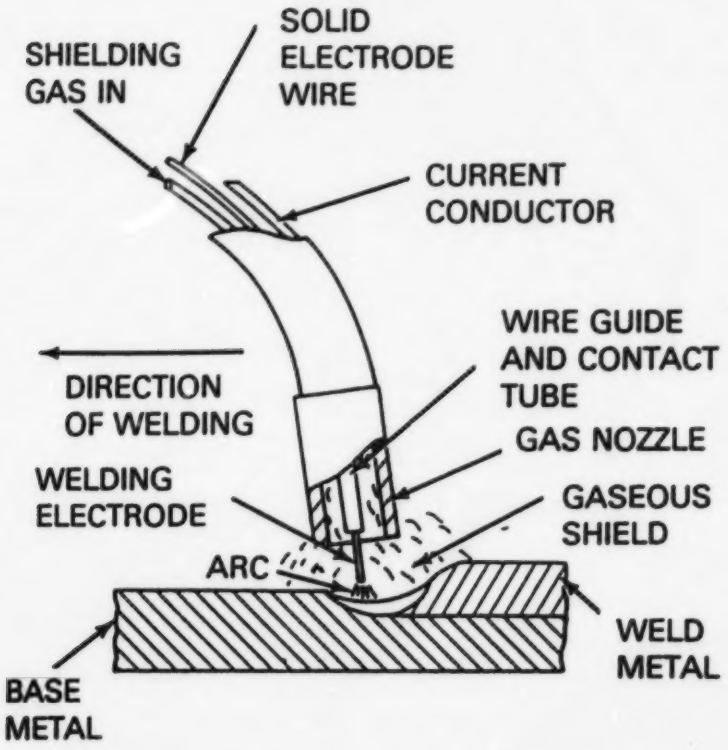

FIGURE B2

GAS METAL ARC WELDING

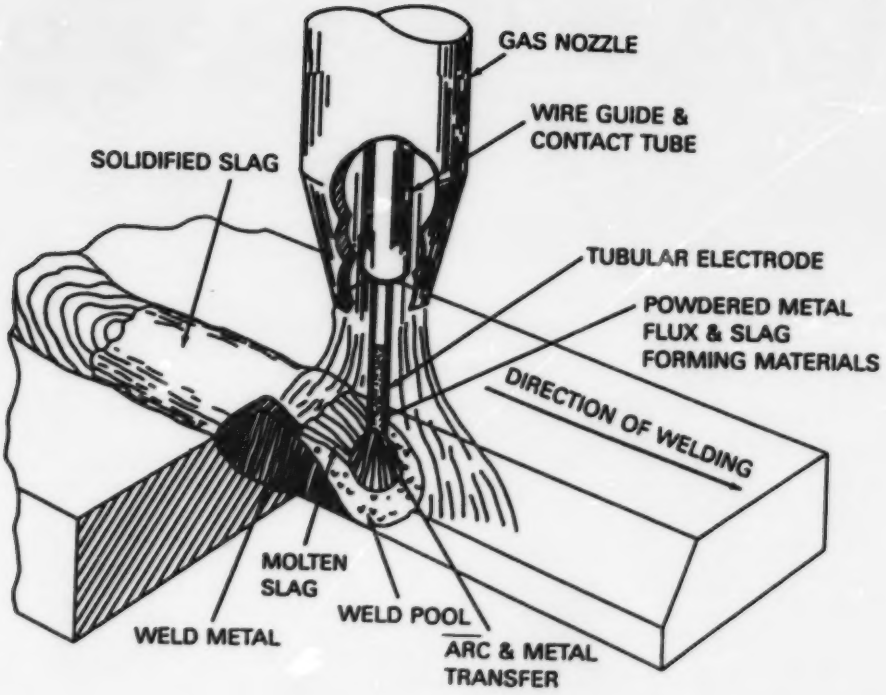

FIGURE B3

GAS SHIELDED FLUX CORED ARC WELDING

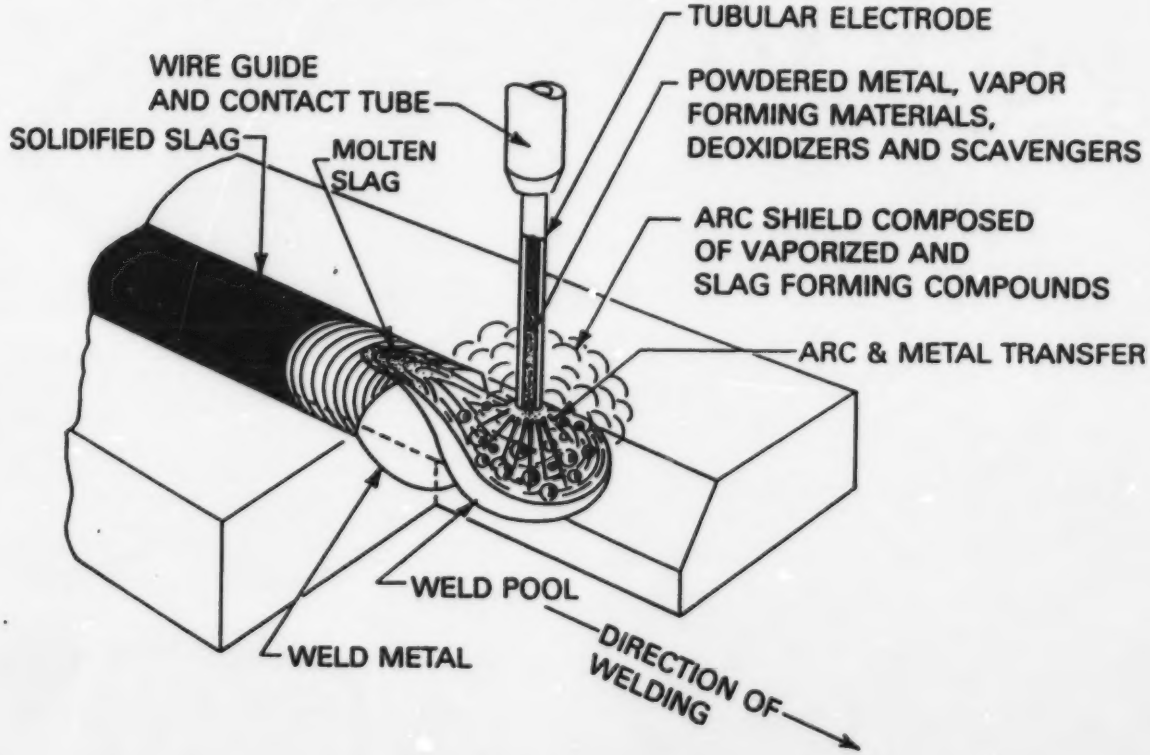

FIGURE B4

SELF-SHIELDED FLUX CORED ARC WELDING

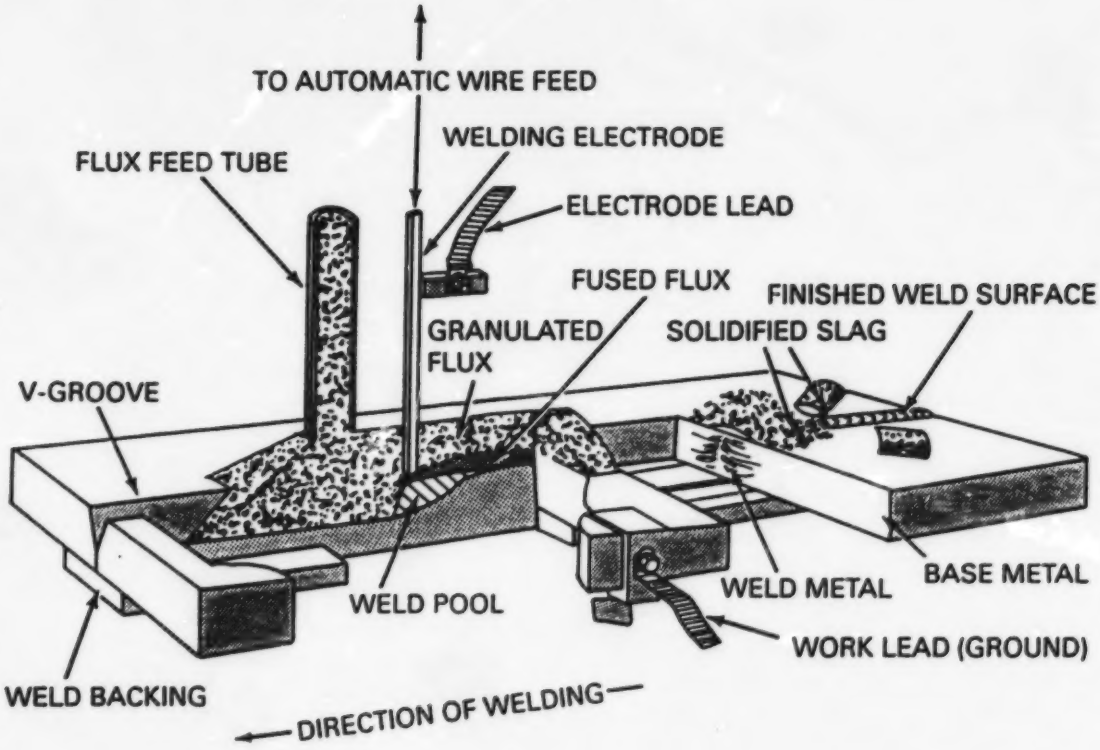

FIGURE B5
SUBMERGED ARC WELDING

APPENDIX C

SOLID STATE POWER SUPPLY DESIGNS AND COMMERCIALLY AVAILABLE GMAW POWER SUPPLIES

TABLE C1 SOLID STATE POWER SUPPLY DESIGNS

Power Source Type	Features
SCR phase control	Simple relatively low cost design enables low power remote and output voltage stabilization. Ripple may be high unless range switch or inductive smoothing is used. Speed of response limited by supply frequency and amount of smoothing.
Transistor series regulator	Excellent accuracy and repeatability, capable of very high response rates and low ripple. Electrical efficiency poor. Relatively high cost design.
Secondary chopper	Uses similar circuit to series regulator but output controlled by switching devices and varying on/off (mark/space) ratio. More electrically efficient than series regulator. Response rate limited by switching frequency but this may be high to provide excellent performance.
Primary rectifier and inverter	Efficient cost effective circuit, excellent performance. Utilizes frequency in range 5 to 50 kHz. Higher frequencies give improved response rates and compact design.
Hybrid designs	Combinations of the above may be used to improve characteristics or provide special process features, eg, square wave AC.

TABLE C2: SOLID STATE GMAW POWER SUPPLIES WITH MULTI-PROCESS CABABILITIES (CANADIAN MARKET)

MANUFACTURER/ MODEL	PRIMARY CONTROL	WELDING SPECIFICATIONS*	MAX. INPUT(60Hz) V/A/PHASES	RATED OUTPUT DUTY CYCLE/A/V	ELEC. EFFIC. kW/kVA	WELD PROGRAMS**
ESAB Pulsed Arc II 400	TRANSISTOR	GMAW-P,GMAW,FCAW, SMAW,GTAW,CV/CC,DC	575/22/3	60%/400/36	89.87%	MS,SS,AL,SB
ESAB Pulsed Arc II 550	TRANSISTOR	GMAW-P,GMAW,FCAW, SMAW,GTAW,CV/CC,DC	575/38/3	60%/550/42	88.00%	MS,SS,AL,SB
FRONIUS Transarc 500	INVERTOR	GMAW-P,GMAW,FCAW, SMAW,GTAW,CV/CC,DC	380/36/3 (575 STEP DOWN)	60%/500/40	N/A	MS,SS,AL, &PROGRAMMABLE
HOBART Megaflex 450	SCR	GMAW,FCAW,SMAW, GTAW,CV/CC,AC/DC	575/28/3	100%/450/38	76.24%	N/A
HOBART Megaflex 650	SCR	GMAW,FCAW,SMAW, GTAW,CV/CC,AC/DC	575/42.5/3	100%/650/44	78.20%	N/A
HOBART Ultra Arc 350	INVERTOR	GMAW-P,GMAW,FCAW, SMAW,GTAW,CC,DC	460/23/3 (575 STEP DOWN)	100%/350/34	78.97%	MS/SS/SB/AL &PROGRAMMABLE
KEMPPI PSS 3500	INVERTOR	GMAW-P,GMAW,FCAW,SM-AW,GTAW,CV/CC,AC/DC	415/30.8/3 (575 STEP DOWN)	60%/350/34	N/A	MS/SS/AL
KEMPPI PSS 5000	INVERTOR	GMAW-P,GMAW,FCAW,SM-AW,GTAW,CV/CC,AC/DC	415/55.4/40 (575 STEP DOWN)	60%/500/40	N/A	MS/SS/AL
LINCOLN Pulse Power 500	SCR	GMAW-P,GMAW,FCAW, SMAW,GTAW,CV/CC,DC	575/36.8/3	100%/500/40	N/A	N/A

continued ...

MANUFACTURER/ MODEL	PRIMARY CONTROL	WELDING SPECIFICATIONS*	MAX. INPUT(60Hz) V/A/PHASES	RATED OUTPUT DUTY CYCLE/A/V	ELEC. EFFIC. kW/kVA	WELD PROGRAMS**
L-TEC Digipulse XRT	INVERTOR	GMAW-P,GMAW,FCAW, SMAW,GTAW,CV/CC,DC	575/32/3	60%/450/38	N/A	MS/SS/AL& PROGRAMMABLE
L-TEC 400i cv/cc	INVERTOR	GMAW,FCAW, SMAW,GTAW,CV/CC,DC	575/29/3	60%/450/38	N/A	N/A
MILLER XMT 300 CC/CV	INVERTOR	GMAW-P,GMAW,FCAW, SMAW,GTAW,CV/CC,DC	460/21/3 (575/?/3)	60/300/32	70.81%	MS/SS/AL/NI/SB
MILLER XMT 200 CC/CV	INVERTOR	GMAW,FCAW, SMAW,GTAW,CV/CC,DC	230/49/1	60/200/28	80.65%	N/A
POWCON 552SMPF	INVERTOR	GMAW-P,GMAW,FCAW, SMAW,GTAW,CV/CC,DC	575/27.6/3	60%/550/42	84.84%	N/A
POWCON 302SMF	INVERTOR	GMAW-P,GMAW,FCAW, SMAW,GTAW,CV/CC,DC	575/16/3	60%/300/32	80.93%	N/A

* PROCESS CABABILITIES & OUTPUT CHARACTERISTICS

** MATERIALS WELDABLE ON STANDARD PROGRAMS
MS=MILD STEEL,SS=STAINLESS STEEL,AL=ALUMINUM,
NI=NICKEL,SB=SILICON BRONZE

APPENDIX D

ENERGY EFFICIENCY TESTING PROCEDURES AND TEST RESULTS

TABLE D1 Energy Efficiency Testing Procedure for Arc Welding

TABLE D2 Energy Efficiency Test Data Sheet

TABLE D3 Description of Welding Power Supplies and Energy Efficiency Testing Parameters

TABLE D4 Specific Energy Values of Welding Consumables

TABLE D5 Electrical Efficiencies of Power Supplies

TABLE D6 Arc-On and Idling Energy Consumption in Arc Welding

TABLE D1 ENERGY-EFFICIENCY TESTING PROCEDURE FOR ARC WELDING

Step 1:	prepare and fill out the following measured data into the test data sheet as shown in Table D2
Step 2:	weigh the test plate and welding electrodes
Step 3:	turn on the welding machine and make sure that no other electrical equipment are withdrawing power from the welding power supply's auxiliary circuits (eg water pump, fume extraction equipment)
Step 4:	record the power output from the welding supply (ie welding voltage and current)
Step 5:	turn on the analyzer and record the idling power of the welding power supply
Step 6:	record the starting weld time on the analyzer print-out
Step 7:	start depositing weld metal onto the test plate; record the arc-on time using a stop watch;
Step 8:	stop welding after a total of 6 minutes of arc-on time; restart welding after 4 minutes
Step 9:	repeat step 7 and step 8 twice (ie accumulate a total of 18 minutes of arc-on time)
Step 10:	record the finishing weld time
Step 11:	weigh the test plate and the welding electrodes
Step 12:	calculate the weight of deposited weld metal and weight of welding electrode used
Step 13:	record the welding power and power factor from the analyzer print-out
Step 14:	calculate the energy-efficiency data from the collected data (see Table D2)

TABLE D2
ENERGY-EFFICIENCY TEST DATA SHEET

Welding Process:
Power Supply:
Welding Parameter:
  welding consumable
  shielding gas
  measured welding voltage(V)
  measured welding current(I)
    output power P(out) = (I/V) = V x I

Weight of test plate before testing =
Weight of test plate after testing =
  weight of deposited weld metal =
weight of welding consumable before testing =
weight of welding consumable after testing =
  weight of welding consumable consumed =

test starting time:
test finishing time:
total testing time t(t) =
arc-on time t(a) =
idling time t(i) = t(t) - t(a) =

real input power (arc-on) kW =
real input power (idling) kW =
apparent input power (arc-on) kVA =
apparent input power (idling) kVA =
power factor (arc-on) =
power factor (idling-on) =
total arc-on and idling energy =
consumption KWH (from analyzer print-out) =

TABLE D3
DESCRIPTIONS OF WELDING POWER SUPPLIES AND ENERGY-EFFICIENCY TESTING PARAMETERS

PS No	PS Description[a] (primary control) maximum input voltage	Specifications[b]	Process Under Study	Welding Paramaters[c]	Welding Consumables
1	Transformer-rectifier PS (Saturable Reactor)	SMAW, TIG, AC, DC, CC, AC/DC	SMAW	DC, RP, 145A, 24V	E7018, 4 mm dia
2	Rectifier PS (SCR)	SMAW, TIG, CC, DC	SMAW	DC, RP, 145A, 24V	E7018, 3.2 mm dia
3	Inverter GMAW PS (Inverter/575V)	SMAW, GMAW, GMAW-P, FCAW, GTAW, CV/CC, DC	SMAW	DC, RP 145A, 23V	E7018, 3.2 mm dia
4	Inverter GMAW PS (Inverter/460V)	SMAW, GMAW-P, GMAW, FCAW, GTAW, CC, DC	SMAW	DC, RP 145A, 24V	E7018, 3.2 mm dia
4	Inverter GMAW PS (Inverter/460 V)	SMAW, GMAW-P, GMAW, FCAW, GTAW, CC, DC	GMAW-P	DC, RP 155A, 23V	ER480-S6, 1.2 mmϕ 75% Ar, 25% CO_2
5	Transistorized MIG PS (Transistor/575V)	GMAW-P, GMAW, FCAW, GTAW, CV/CC, DC	GMAW-P	DC, RP 155A, 22.5V	ER480-S6, 1.2 mmϕ 82% AR, 8% CO_2

TABLD D3 (Continued)
DESCRIPTIONS OF WELDING POWER SUPPLIES AND ENERGY-EFFICIENCY TESTING PARAMETERS

PS No	PS Description[a] (primary control) maximum input voltage	Specifications[b]	Process Under Study	Welding Paramaters[c]	Welding Consumables
6	Rectifier PS (SCR/575V)	GMAW, FCAW, CV mode	Spray-transfer, GMAW	DC, RP 250A, 29V	ER480-S6, 1.2 mm dia 90% Ar, 10% CO_2
6	Rectifier PS (SCR/575V)	GMAW, FCAW, CV mode	Gas-shielded FCAW	DC,RP 175A, 24V	E480-T1, 9CH, 1.2mm dia 75% AR, 25% CO_2
6	Rectifier PS (SCR/575V)	GMAW, FCAW, CV mode	Self-shielded FCAW	DC, RP 390A, 30V	E70T-4, 2.4 mm dia
7	Rectifier PS (SCR/575V)	SAW, SMAW, CV/CC, DC	Single-wire SAW	DC, RP 710A, 32V	EM12K, 4.0 mm dia
7	Rectifier PS (SCR/575V)	SAW, SMAW, CV/CC, DC	Twin-wire SAW	DC, RP 710A, 27.7V	EM12K, 2.4 mm dia

[a] primary control for the power supply output; maximum input voltage that can be accommodated by the power supplies
[b] AC - alternating current; DC - direct current; CV - constant voltage; cc - constant current
[c] RP - reverse polarity

TABLE D4
SPECIFIC ENERGY VALUES OF WELDING ELECTRODES

PS No	PS Description	Process	Operator Factor	Specific Energy of Welding Electrodes KWH/lb Arc-On	Idling	Total	Mean Specific Energy of Welding Consumable KWH/lb
1	Transfer Rectifier	SMAW	0.3	3.18	1.29	4.47	SMAW $\frac{(4.47+5.54) \times 0.75}{2} + \frac{(0.88+1.54) \times 8.25}{2}$ = 4.05
2	Rectifier PS (SCR)	SMAW	0.3	1.28	4.26	5.54	
3	Inverter GMAW PS	SMAW	0.3	0.81	0.07	0.88	
4	Inverter PGMAW PS	SMAW	0.3	0.83	0.71	1.54	
4	Inverter GMAW PS (Inverter/460 V)	GMAW-P	0.5	1.08	0.06	1.14	GMAW $\frac{(1.14 + 0.96) \times 0.33}{2} + 1.1 \times 0.66$ = 1.07
5	Transistorized GMAW PS (Transistor/575V)	GMAW-P	0.5	0.93	0.03	0.96	
6	Rectifier (SCR/575V)	GMAW	0.5	0.97	0.13	1.1	
6	Rectifier (SCR/575V)	Gas shielded FCAW	0.5	0.96	0.19	1.15	FCAW $\frac{1.15 + 1.12}{2}$ = 1.14
6	Rectifier (SCR/575)	Self-shielded FCAW	0.5	1.03	0.09	1.12	
7	Rectifier (SCR/575V)	Single-Wire SAW	0.5	1.59	0.13	1.72	SAW = 1.72
7	Rectifier (SCR/575V)	Twin wire SAW	0.5	1.16	0.11	1.27	

TABLE D5
ELECTRICAL EFFECIENCIES AND POWER CONSUMPTION DATA FOR ARC WELDING POWER SUPPLIES

PS No	PS Description	Process	Arc-On						Idling		
			Real Power (kW)	Power Factor	Apparent Power (kVA)	Output Power (kW)	Electrical Efficiency $\frac{\text{Output Power}}{\text{Real Power Input}}$	% Loss of Input Real Power	Real Power (kW)	Power Factor	Apparent Power (kVA)
1	Transformer-Rectifier (Saturable Reactor)	SMAW	18.86	.74	25.49	3.48	18.5%	81.5%	2.052	.98	2.09
2	Rectifier PS (SCR)	SMAW	10.06	.98	10.26	3.48	34.6%	65.4%	4.814	.99	4.86
3	Inverter GMAW PS (Inverter/575V)	SMAW	3.87	.99	3.91	3.48	89.9%	10.1%	0.069	.58	0.12
4	Inverter GMAW PS (Inverter/460V)	SMAW	4.35	.62	7.02	3.48	80.0%	20%	0.716	.40	1.79
4	Inverter GMAW PS (Inverter/460V)	GMAW-P	5.60	.58	9.66	3.56	63.6%	36.4%	0.312	.20	1.56
5	Transistorized GMAW PS (Transistor/575V)	GMAW-P	4.80	.97	4.95	3.49	72.7%	27.3%	0.126	.42	0.30
6	Rectifier (SCR/575V)	GMAW	8.89	.46	19.33	7.25	81.6%	18.4%	0.987	.45	2.19
6	Rectifier (SCR/575V)	Gas-Shielded FCAW	6.32	.40	15.80	4.20	66.5%	33.5%	0.984	.43	2.29
6	Rectifier (SCR/575V)	Self-Shielded FCAW	14.83	.49	30.26	11.70	78.9%	21.1%	0.987	.45	2.19
7	Rectifier (SCR/575V)	Single-Wire SAW	33.74	.54	62.48	22.72	67.3%	32.7%	2.692	.26	10.35
7	Rectifier (SCR/575V)	Twin Wire SAW	31.24	.50	62.48	19.67	63.0%	37.0%	2.632	.26	10.12

TABLE D6
ENERGY CONSUMPTION DATA FOR ARC WELDING

PS No	PS Description	Process	Real Arc-On kW	Power Idling kW	Operator Factor	Time Req'd per lb of deposited weld metal (Hour)			Energy Req'd per lb of deposited weld metal KWH		
						Arc-On	Idling	Total	Arc-On	Idling	Total
1	Transformer-Rectifier (Saturable Reactor)	SMAW	18.86	2.05	0.1 0.3	0.27 0.27	2.43 0.63	2.70 0.90	5.09 5.09	4.98 1.29	10.07 6.38
2	Rectifier PS (SCR)	SMAW	10.06	4.81	0.1 0.3	0.38 0.38	3.42 0.89	3.80 1.27	3.82 3.82	16.46 4.26	20.28 8.09
3	Inverter GMAW PS (Inverter/575V)	SMAW	3.87	0.07	0.1 0.3	0.43 0.43	3.87 1.00	4.30 1.43	1.66 1.66	0.27 0.07	1.94 1.73
4	Inverter GMAW PS (Inverter/460V)	SMAW	4.35	0.72	0.1 0.3	0.42 0.42	3.78 0.98	4.20 1.40	1.83 1.12	0.71 0.71	4.56 2.54
4	Inverter GMAW PS (Inverter/460V)	GMAW-P	5.60	0.31	0.3 0.5	0.20 0.20	0.47 0.2	0.67 0.40	1.12 1.12	0.15 0.06	1.27 1.18
5	Transistorized GMAW PS (Transistor/575V)	GMAW-P	4.80	0.13	0.3 0.5	0.20 0.20	0.47 0.20	0.67 0.40	2.96 0.96	0.06 0.03	1.02 0.99
6	Rectifier (SCR/575V)	GMAW	8.89	0.99	0.3 0.5	0.13 0.13	0.30 0.13	0.43 0.26	1.16 1.16	0.30 0.13	1.46 1.28
6	Rectifier (SCR/575V)	Gas-Shielded FCAW	6.32	0.98	0.3 0.5	0.19 0.19	0.44 0.19	0.63 0.38	1.20 1.20	0.43 0.19	1.63 1.39
6	Rectifier (SCR/575V)	Self-Shielded FCAW	14.83	0.99	0.3 0.5	0.09 0.09	0.21 0.09	0.30 0.18	1.33 1.33	0.21 0.09	1.54 1.42
7	Rectifier (SCR/575V)	Single-Wire SAW	33.74	2.69	0.3 0.5	0.049 0.049	0.114 0.049	0.163 0.098	1.65 1.65	0.31 0.13	1.96 1.79
7	Rectifier (SCR/575V)	Twin Wire SAW	31.24	2.63	0.3 0.5	0.043 0.043	0.101 0.043	0.144 0.086	1.35 1.34	0.27 0.11	1.61 1.46